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(Anti)hypertriton lifetime puzzle

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Abstract

Most calculations on the lifetime of (anti)hypertriton gave a similar lifetime which is close to the lifetime of free Λ decays. However, recent measurements on (anti)hypertriton lifetime demonstrate a much short lifetime. All results for (anti)hypertriton lifetime by two-body decay channel of ^3He + π for Au+Au collision at RHIC, Pb+Pb collision at LHC and Li + C collisions at GSI show a significant short lifetime in comparison with lifetime of free Λ decays. However, theoretical interpretation remains puzzle.

Hypernucleus provides an ideal environment to learn the hyperon-nucleon interaction, which is responsible partly for the binding of hypernuclei and lifetime. Therefore, a meaurement of the precise lifetime of hypernucleus could provide a tool to investigate of hyeron-nucleon interaction [1–7]. The most simple hypernucleus is hypertriton, which is a bound state of a proton, a neutron, and a hyperon (Λ or Ξ), it is bound with respect to the Λ-d threshold by 0.136±0.05 MeV. In 2010, ${}^3_{\bar{\Lambda}}\overline{\mathrm{H}}$, the antimatter partner of ${}^3_\Lambda$H, has been discovered at RHIC-STAR as the first antimatter hypernucleus [8] . The hypertriton decays weakly into mesonic and nonmesonic channels. The nonmesonic decay channels are ${}^3_\Lambda\mathrm{H} \rightarrow$ d + n and ${}^3_\Lambda\mathrm{H} \rightarrow$ p + n +n. In the mesonic decay mode there are more channels: ${}^3_\Lambda\mathrm{H} \rightarrow \pi^-(\pi^0) + {}^3\mathrm{He}({}^3\mathrm{H})$, ${}^3_\Lambda\mathrm{H} \rightarrow \pi(\pi^0)$ + d + p(n), and ${}^3_\Lambda\mathrm{H} \rightarrow \pi(\pi^-)$ + p + n + p(n). In contrast to heavier hypernuclei, where mesonic decays are Pauli blocked, here in the hypertriton they are by far the dominant ones. Further there are experimental data on the branching ratio $R = \Gamma({}^3_\Lambda\mathrm{H} \rightarrow \pi^- + {}^3\mathrm{He})/\Gamma({}^3_\Lambda\mathrm{H} \rightarrow$ all π^- meson modes) ranging between 0.30 ± 0.07 [9] and 0.39 ± 0.07 [10]. From the technique viewpoint in heavy-ion collision, a simple identification method of ${}^{3}_{\Lambda}$H (${}^{3}_{\Lambda}\overline{\mathrm{H}}$) can be achieved by reconstructing their secondary vertex via the decay channel of ${}^{3}_{\Lambda}\mathrm{H} \rightarrow {}^{3}\mathrm{He} + \pi^{-}$ (${}^{3}_{\Lambda}\overline{\mathrm{H}} \rightarrow {}^{3}\overline{\mathrm{He}} + \pi^{+}$), which occurs with a branching ratio of 25% (assuming that this branching fraction is the same as that for ${}^{3}_{\Lambda}$H [2]) [8, 11, 12]. In contrast, reconstruction of ${}^{3}_{\Lambda}$H (${}^{3}_{\Lambda}\overline{\mathrm{H}}$) from three-body decay, i.e. ${}^{3}_{\Lambda}\mathrm{H} \rightarrow \pi(\pi^{0}) + \mathrm{d} + \mathrm{p(n)}$, is more complicate, but it deserves to check with two-body decay results, and it is under progress well [13].

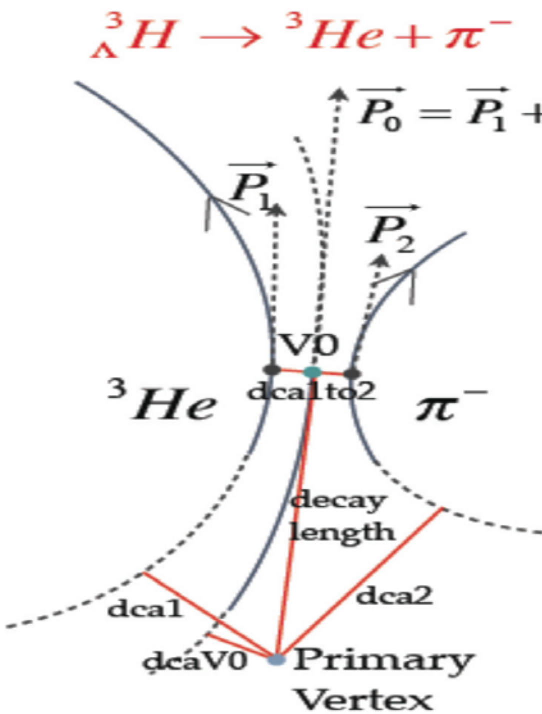

Figure 1: Topological decay map for 2-body channel of ${}^{3}_{\Lambda}$H.

Theoretically, most of calculations predicted that the hypertriton lifetime is a littler shorter than the free Λ lifetime since it could exhibit the modification of the Λ wavefunction in the nuclear medium. For an example, the π-mesonic decay of the hypertriton is calculated based on a hypertriton wave function and 3N scattering states, which are solutions of three-body Faddeev equations using realistic NN and hyperon-nucleon interactions [14]. They predicted that the total lifetime of ${}^{3}_{\Lambda}$H is 256 ps which is 3% smaller than for the free Λ particle [14].

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In this work, the lifetime measurement data for ${}^3_\Lambda$H (${}^3_\Lambda\overline{\mathrm{H}}$) two-body decay from Au + Au collisions at RHIC is reported. The data was collected by the STAR experiment at RHIC, using the cylindrical TPC, which is 4 meters in diameter and 4.2 meters long in the beamline direction [15]. The identification of tracks can be achieved by correlating their ionization energy loss $\langle dE/dx \rangle$ in TPC with their magnetic rigidity.

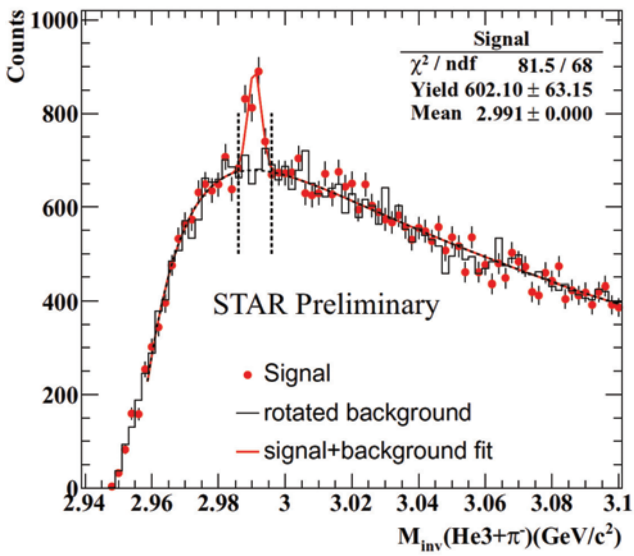

Figure 2: Reconstructed invariant mass distribution of ${}^3_\Lambda$H from two-body decay channel of ^{3}He. Solid circles stand for the signal distribution, while dashed lines are the rotated combinatorial background. Vertical dashed lines represent the mass range we use for bin counting of ${}^3_\Lambda$Hyield. Adapted from Ref. [12].

For two-body decay channel, topological cuts include the distance between two daughter tracks ^{3}He (${}^3\overline{\mathrm{He}}$) and $\pi^-(\pi^+)$ (<1cm), distance of closest approach (DCA) between ${}^3_\Lambda$H (${}^3_\Lambda\overline{\mathrm{H}}$) and primary vertex (<1cm), decay length of ${}^3_\Lambda$H (${}^3_\Lambda\overline{\mathrm{H}}$) (>2.4cm), and the DCA of π track (>0.8cm), are employed to enhance the signal to background ratio [12]. Figure 1 shows the topological decay maps for both 2-body channel. The invariant mass of ${}^3_\Lambda$H (${}^3_\Lambda\overline{\mathrm{H}}$) was calculated based on the conservation of momentum and energy in the decay process. The result is shown in Figure 2. The successfully reproduced combinatorial background with a rotation strategy can be described by double exponential function: $f(x) \propto exp[-(x/p_1)] - exp[-(x/p_2)]$, where $x = m - m({}^3He) - m(\pi)$, and p_1, p_2 are the free parameters. Finally, the signals are counted by subtracting the double exponential background of ${}^{3}_{\Lambda}\mathrm{H}$ and ${}^{3}_{\Lambda}\overline{\mathrm{H}}$.

To demonstrate a visual scenario for ${}^{3}_{\Lambda}\mathrm{H}$ decay, a carton picture is depicted to help us understand the possible decay mechanism. Figure 3 shows a possible decay process of two-body decay of ${}^{3}_{\Lambda}\mathrm{H}$, which can be understood by a capture of decayed proton from Λ by the existed neutron and proton inside ${}^{3}_{\Lambda}\mathrm{H}$, resulting in a final decayed products ${}^{3}He$ and π .

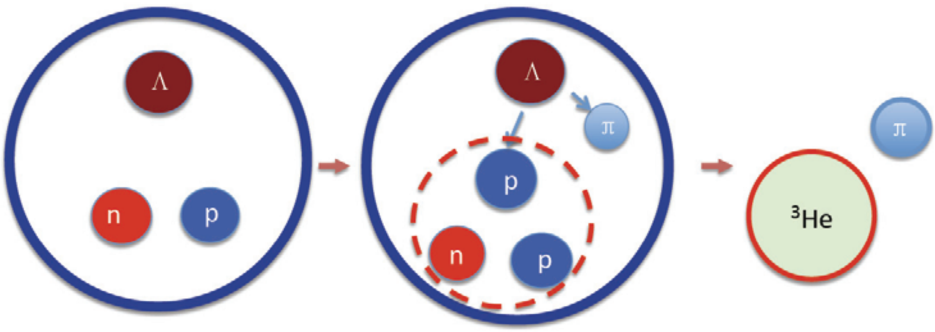

Figure 3: Cartons for ${}^{3}_{\Lambda}\mathrm{H}$ (${}^{3}_{\Lambda}\overline{\mathrm{H}}$) two-body decay channel of ${}^{3}\mathrm{He}+\pi$.

The above secondary vertex reconstruction of ${}^{3}_{\Lambda}\mathrm{H}$ (${}^{3}_{\Lambda}\overline{\mathrm{H}}$) allows ones to perform a calculation of its lifetime, via equation $N(t) = N(0)exp(-t/\tau)$, where $t = l/(\beta\gamma c)$, $\beta\gamma c = p/m$, l is the decay length of ${}^{3}_{\Lambda}\mathrm{H}$, p is their momentum, m is their mass value, while c is the speed of light. ${}^{3}_{\Lambda}\mathrm{H}$ and ${}^{3}_{\Lambda}\overline{\mathrm{H}}$ samples are combined together to get a better statistics, with the assumption of the same lifetime of ${}^{3}_{\Lambda}\mathrm{H}$ and ${}^{3}_{\Lambda}\overline{\mathrm{H}}$ based on the CPT symmetry theory. The measured yield is corrected for the tracking efficiency and acceptance of TPC, as well as the reconstruction efficiency of ${}^{3}_{\Lambda}\mathrm{H}$ and ${}^{3}_{\Lambda}\overline{\mathrm{H}}$. Then, the $l/(\beta\gamma)$ distribution can be fitted with an exponential function to extract the lifetime parameter $c\tau$.

The RHIC beam energy scan program in 2010-2011 allowed STAR to collect data for Au+Au collisions over a broad range of energies. To get an even better statistics, datasets are combined in the lifetime measurement. For two-body decay, the best fitting with χ^2 minimization method gives a value of $c\tau = 3.69\pm^{0.77}_{0.65}$ cm, which corresponds to a lifetime of $123 \pm ^{26}_{22}$ (stat) $\pm$ 10(sys) ps (Fig. 4) [12]. As a comparison, STAR 2010 ${}^{3}_{\Lambda}\mathrm{H}$ lifetime measurement [8] and the STAR 2010+2012 combined results are also provided. The current measurement is consistent with the STAR 2010 measurement within 1.5σ and is statistically improved. In this lifetime measurement, two kinds of sources for systematic study are considered: 1. choice of V0 topol-

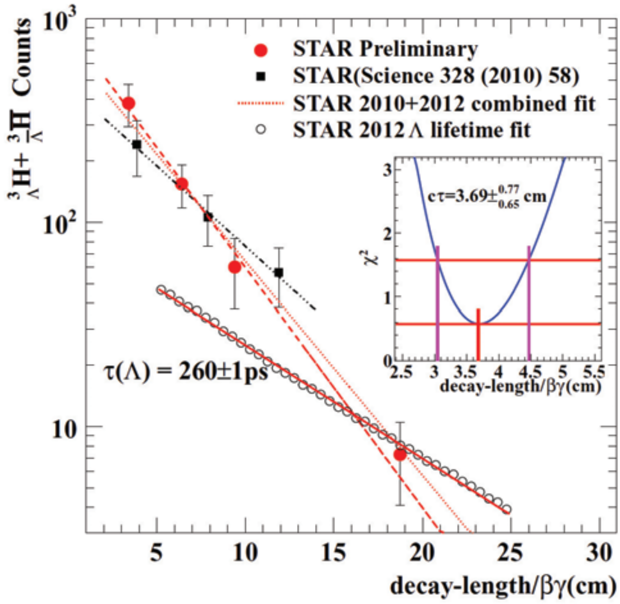

Figure 4: The yields of ${}^3_\Lambda$H+ ${}^3_\Lambda\overline{\rm H}$ and Λ (open circles) vs $c\tau$ distribution. The solid lines stand for the $c\tau$ fits, and the insert plot describes χ^2 distribution of the best fits. Comparison between the present measurement and the previous measurements is also demonstrated. Adapted from Ref. [12].

ogy cuts; 2. choice of bin width and invariant mass range. These effects contribute to the final systematic error. Additional sources of loss, like the interaction between ${}^3_\Lambda$H and material (air+detector) are also considered, which can be neglected due to its less than 1.5% effect [12]. As a further cross-check, Λ is reconstructed via the $\Lambda \rightarrow p + \pi^-$ decay channel. To this end, the same method is adopted to obtain the Λ lifetime and the result is 260 $\pm$ 1 ps which is consistent with the τ = 263 $\pm$ 2 ps compiled by the Particle Data Group [16]. In this way, we confirm that the method to extract ${}^3_\Lambda$H (${}^3_\Lambda\overline{\rm H}$) lifetime is reliable.

In summary, with the current highest statistics of (anti-)hypertriton samples, the results of STAR measurement definitely gives a short lifetime from two-body decay channel, $123^{+26}_{-22}ps$, which is much shorter than the free Λ decay lifetime. Also, recent measurements of ALICE collaboration for Pb + Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV show $\tau = 181^{+54}_{-39}$ (stat.) $\pm$ 33 (syst.) ps for ${}^3_\Lambda$H lifetime [17] and HypHI Collaboration for ^{6}Li projectiles at 2A GeV on a carbon target also gave $\tau = 183^{+42}_{-32} \pm 37$ ps for ${}^3_\Lambda$H lifetime [18]. All these results are consistent within the errors and demonstrated that

${}^{3}_{\Lambda}$H (${}^{3}_{\Lambda}\overline{\mathrm{H}}$) decay has a significant short lifetime than theoretical expected values. Therefore an open question remains for theoretical interpretation, which still leave us a puzzle for understanding the structure of ${}^{3}_{\Lambda}$H (${}^{3}_{\Lambda}\overline{\mathrm{H}}$) and hyperon-nucleon interaction.

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References

[1] R. H. Dalitz, G. Rajasekharan, Phys. Lett. **1**, 58 (1962)

[2] H. Kamada, J. Golak, K. Miyagawa, H. Witala, W. Glockle, Phys. Rev. C **57**, 1595 (1998)

[3] B. F. Gibson, E.V. Hungerford III, Phys. Rep. **257**, 349 (1995)

[4] E. Oset, P. Fernandez de Cordoba, L.L. Salcedo, R. Brockmann, Phys. Rep. **188**, 79 (1990)

[5] E. Hiyama, T. Motoba, T. A. Rijken and Y. Yamamoto, Progress of Theoretical Physics Supplement **185**, 1 (2010)

[6] A. S. Botvinaa, J. Steinheimer, E. Bratkovskaya, M. Bleicher, J. Pochodzalla, Phys. Lett. B **742**, 7 (2015)

[7] H. Shen, J. S. Liang, Nuclear Techniques (in Chinese) **37** , 100507 (2014)

[8] B. I. Abelev *et al.* (STAR Collaboration), Science **328** , 58 (2010)

[9] G. Keyes *et al.*, Phys. Rev. D **1**, 66 (1970); Phys. Rev. Lett. **20**, 819 (1968); Nucl. Phys. B **67**, 269 (1973)

[10] M. Block *et al.*, in Proceedings of the Sienna International Conference on Elementary Particles, edited by G. Bernandini and G. P. Puppi Societa de Fisica, Bologna, 1963, p. 62.

[11] J. H. Chen, Nucl. Phys. A **835**, 117 (2010); Nucl. Phys. A **830** , 761c (2009)

[12] Y. H. Zhu, Nucl. Phys. A **904-905**, 551c (2013); PhD Thesis (2013), Shanghai Institute of Applied Physics, CAS, 2013.

[13] Y. F. Xu for the STAR Collaboration, the talk at the 12th International Conference on Hypernuclear and Strange Particle Physics (HYP2015), Sept 2015, Sendai, Japan.

[14] H. Kamada, J. Golak, K. Miyagawa, H. Witala, and W. Glöckle, Phys. Rev. C **57**, 1595 (1998)

[15] M. Anderson *et al.*, Nucl. Instrum. Methods A **499**, 659 (2003)

[16] C. Amsler *et al.*, Phys. Lett. B **667**, 1 (2008)

[17] J. Adam *et al.* (ALICE Collaboration), arXiv:1506.08453.

[18] C. Rappold, E. Kim, D. Nakajima, T. Saito, O. Bertini *et al.* (HypHI Collaboration), Nucl. Phys. A **913**, 170 (2013)